Chapter Six
A Human Factors Guide For Aviation Maintenance

6.0 INTRODUCTION

The U.S. air carrier industry and the Federal Aviation Administration are dedicated to the highest level of safety in commercial aviation. To achieve this goal, they must rely on effective and efficient maintenance operations. Proper maintenance support is indispensable to safety, to aircraft availability, and to airline profitability. The safety requirements dictate that maintenance be effectively error-free. Aircraft inspectors and aircraft mechanics must work in an environment and use procedures and equipment all carefully structured to work well and to minimize any potential for error. The **design** of procedures and equipment must ensure that errors are not built into the system.

The maintenance effort to ensure continuing airworthiness of the air carrier fleet is demanding and costly. The maintenance industry continues to grow in parallel with that of airline operations. Table 6.1 shows that, in 1991, about 59,000 mechanics were employed in this industry, with maintenance expenses of approximately $9 billion. These numbers reflect significant growth over the last decade but do not indicate the changing character of the industry. Maintenance operations are being recast to account for the introduction of new and more complex aircraft and the use of more sophisticated maintenance and inspection procedures.

Mechanics employed	=	58,819
Maintenance expenses	=	$8.8 billion (11.5% of operating expenses)
Major carriers contract approximately 11% of maintenance work		

Table 6.1 **Maintenance Parameters for U.S. Scheduled Airlines (1991 data)** *ATA (1992); Office of Technology Assessment (OTA) (1988).*

Aviation maintenance is in fact a large industrial system which includes many elements such as the aircraft, the maintenance facility, supervisory forces, inspection equipment, repair equipment, and the maintenance technician. All of these elements together comprise the "maintenance system" (Figure 6.1). Within this system, the technician functions and should be viewed as one would view any other element. A maintenance technician has a set of operating characteristics. Conceptually this **human** can be considered in essentially the same manner as other system elements such as, for example, items of electronic equipment. The major difference is that the **human** is significantly more complex and not nearly as predictable. However, anyone responsible for **designing** or operating a system, such as a maintenance system, must understand the operating characteristics of each element within the system, and this includes the **human**.

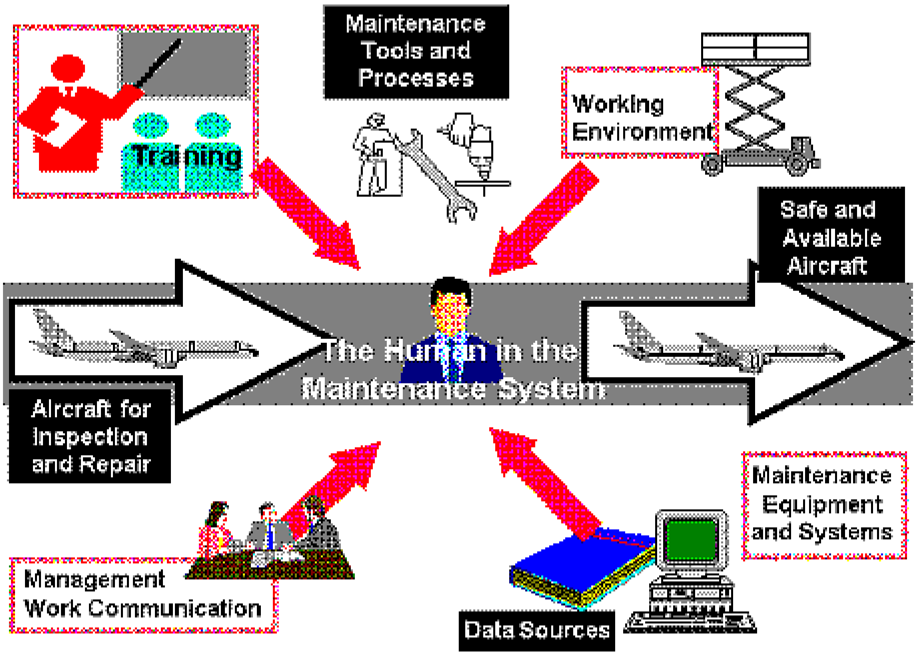

Figure 6.1 The Maintenance System

Human factors is a discipline which seeks to understand the laws of **human** behavior, the capabilities and limits of **humans**, and the effects of environmental and other **factors** on **human** behavior. A key goal of **human factors** is to provide guidelines for the optimum use of **humans** in operating systems. An allied goal is to define the manner in which variables internal and external to a system affect **human** performance within the system.

The operation of any system can only be optimized if every system element is working properly and if each element is carefully coordinated with every other element. The manager of a system such as a maintenance operation should have all necessary information concerning maintenance technicians and, in particular, those features of the maintenance environment which serve either to enhance or to degrade technician performance. The manager or supervisor of a maintenance activity can be aided through use of a **Human Factors Guide** that will provide this information in a form suitable for day-to-day reference use.

A **Human Factors Guide** will present established principles of job **design** and work. These principles, if well applied, can make a major contribution toward the control of **human** error in aircraft maintenance and inspection. Issues of communications, equipment utilization, work scheduling and load, work environment, and management relations all are of importance in determining worker effectiveness. A **Human Factors Guide** should cover these and other issues of **human** performance that can be applied in aviation maintenance. In presenting these principles, the **Guide** should see that the information is especially addressed to aviation maintenance and inspection needs.

The preparation of a **Human Factors Guide** is timely for a number of reasons. The most important of these reasons include:

1. There is a need. Safety is always a matter of concern. The **Guide** can contribute to maintenance efficiency and to the control of **human** error in maintenance. This in turn will support continuing safety. There also is the matter of cost control. Maintenance effectiveness contributes to cost reduction.

2. **Human factors** is a mature and growing discipline. The knowledge within this discipline should be used to support maintenance operations in the same manner as

information from the engineering sciences support specific maintenance procedures.

3. Considerable information concerning **human factors** in aviation maintenance has been developed both through the research conducted by the OTA **Human Factors** Team and through the conduct of **human factors** meetings during which beneficial recommendations have been made by representatives of air carrier maintenance. All of this information should be incorporated into a **Human Factors Guide**.

The **Human Factors Guide**, as envisioned now, will be directed primarily toward those concerned with the development and operation of air carrier maintenance organizations. However, the **Guide** will be structured to meet the needs also of a larger audience interested in and responsible for aviation maintenance. In general, the **Guide** should provide **human factors** principles and data of use to:

Maintenance planners and supervisors

Maintenance inspectors and technicians

OTA management and OTA inspectors

Air carrier operators

Designers of maintenance equipment

Aircraft **design** teams

Aircraft manufacturers

6.1 DEVELOPMENT OF A HUMAN FACTORS GUIDE

The development of a **Human Factors Guide** for Aviation Maintenance is underway. The first step in this development was to consider the premise on which the **Guide** should be constructed. This premise is that the **Guide**, or any such document, is of little if any value if it is not used. The aviation maintenance community must use the **Human Factors Guide** if the **Guide** is to serve any real purpose. For the **Guide** to be used, it must meet ongoing needs of maintenance personnel and must be prepared in such a manner as to foster use by this group.

In order to collect information to satisfy the above requirements, a sampling of aviation maintenance personnel was conducted. The information solicited was **designed** to ensure that the real needs of maintenance personnel would be met and that the **Guide** could be consistent with the ways in which this sample stated they were likely to use such a **Guide**.

Approximately 60 individuals affiliated in some manner with the air carrier maintenance industry were contacted to provide guidance on significant maintenance topics. Names were selected from the list of attendees at earlier OTA **Human Factors** Meetings. The list included persons both from the United States and from foreign countries. The role of these persons in aviation maintenance, based on their replies, is shown in Table 6.2. The fact that most replies were received from "Inspection/ Maintenance Managers" is to be expected since this job category constituted the bulk of the initial mailing.

Work Classification	Number
Inspection/Maintenance Manager	22
Educator/Trainer	7
Aircraft Designer	2
Other (Senior Management, Quality Assurance, Consultant, Research, AMT Associate, Crew Systems Analyst)	7

Table 6.2 Occupation of Respondents

The next question concerned the value users would place on a **Human Factors Guide** for their work. Not surprisingly, almost all of those who replied indicated a **Human Factors Guide** would be "very valuable" or "valuable." Since these replies were given by persons who had evidenced interest in this topic by attending **human factors** meetings, these replies were anticipated.

The individuals were questioned on the anticipated frequency of use for a **Human Factors Guide**, if the **Guide** contained appropriate information. This question was asked in order to determine whether the **Guide** should be prepared as a working document (as a job aid) or as a reference manual. Table 6.3presents the replies to this question.

Frequency of Use	Number of Replies
Review initially	1
Daily	3
Weekly	20
Monthly	13
Rarely	1

Table 6.3 Frequency of Anticipated Use for a Human Factors Guide

The replies indicate the preferred use for a **Human Factors Guide** would be as a working document consulted on a number of occasions during the year.

6.2 HUMAN FACTORS COVERAGE

The coverage provided in a **Human Factors Guide** is of great importance if the **Guide** is to be truly useful. Certainly, the topics included in this **Guide** should be those which members of the maintenance community consider important. In order to collect information concerning desired coverage, an outline of a prototype **Guide** was prepared. Each person was presented a list of chapter headings from the prototype outline and asked to judge the importance of the topic on a five-step scale ranging from "very important" (weighting of five) to "not important" (weighting of one). With this system, had each of the respondents judged a given topic to be "very important," that topic would have received a total score of 190. Results for this question are presented in Table 6.4. While there is a dispersion of total scores, it is quite apparent that most topics were judged either as "very important" or "important." The topics in Table 6.4 are listed in terms of decreasing order of judged importance.

Topic	Weighted Score
Human Error in Maintenance	178
Information Exchange and Communications	178
Maintenance Training and Practices	173
Human Capabilities and Limits	169
Human Performance	166
Work Requirements	163
The Maintenance Workplace	160

Table 6.4 Importance of Specific Topics for Inclusion in a Human Factors Guide

Prior to the contact with the 60 individuals, a question had arisen about the desirability of including a section within the **Human Factors Guide** concerning emotional **factors**. For this reason, a separate question was included that asked "Should the **Human Factors Guide** contain a section, not usually included in texts of this type, that addresses social and emotional **factors** that can affect the performance of a worker?" The following responses were received:

Yes = 32 **No** = 6

Obviously, the majority of the respondents believe that a section containing the above information should be included in the **Guide**.

To ensure that no appropriate topics were missed, each respondent was asked to note any additional topics believed important for a **Guide** of this type. Quite a few replies were received; most appeared to be variants of the topics in the initial list presented in the mailing. However, a few were indeed new and are listed below:

1. Requalification, limitations, and competency verification for aviation maintenance technicians.
2. Minimum individual qualifications (eyesight, color blindness, and manual dexterity) for specific maintenance functions.
3. Sexual harassment. (This could become increasingly important as workforce demographics change.)
4. Working with the handicapped. (The recently passed Americans With Disabilities Act gives impetus to this topic.)

6.3 FORMAT

For a **Guide** to be useful, it not only must contain appropriate information but also must be presented in a manner **designed** to make it easy to use. Several questions addressed the general issue of format. The first question concerned optimum length. The contacted individuals were asked "To be most usable, what size should a **Human Factors Guide** be?" Table 6.5 presents the responses.

Length	Responses
Less than 100 pages	18
100 - 300 pages	14
Over 300 pages	0
Size is of no concern	6

Table 6.5 Desired Length of a Human Factors Guide

The above replies clearly point to a shorter rather than a longer **Guide**. These data are supported by a comment submitted by one respondent:

> *A Human Factors Guide should be 50-75 pages for handout to line management personnel. It should be 100-300 pages for managers and supervisors with decision making capabilities for resources and monies.*

The next item asked "What format would you find most useful?" This question is considered quite important since the manner in which information is presented can affect the extent to which individuals will seek and use information concerning the topic being presented. Table 6.6 shows the results for this question.

Format	Number of Selections
Key information and recommendations in bullet form, with illustrations	20
Short statements, with illustrations	8
Running prose, with illustrations	8
Other (Please Specify) (Combine short statements, with illustrations, and key information and recommendations in bullet form, with illustrations; use running prose - segmented by topic statements; use electronic/digital format with key word search.)	2

Table 6.6 Preferred Format for a Human Factors Guide

Results indicate the desired format would be one in which information is presented tersely and concisely, either in bullet form or using short statements. Illustrations should support the materials as needed.

A question next was asked which relates both to the length of the **Guide** and the manner in which materials are presented. Two alternatives were given with a request for a preference between these two. Table 6.7 lists the two alternatives and shows the replies.

Alternatives	Number
A shorter guide, presenting brief discussions and recommendations, with supporting data elsewhere (possibly in another book or in a computer data base)?	21
A longer guide, with supporting data included as appendices?	17

Table 6.7 Preference for Physical Structure of a Human Factors Guide

These results show a slight preference for a shorter **Guide**, even if one has to look elsewhere for data supporting and elaborating the concise information presented in the **Guide**. One supporting comment illustrates this: "A shorter **Guide**. Computerized supporting data would be very nice."

6.4 SUMMARY

The replies of the maintenance personnel, combined with other discussions with those likely to use a **Human Factors Guide**, lead to the following conclusions concerning the content and structure of the **Guide**.

Audience. The principal users of a **Human Factors Guide** will be air carrier maintenance planners and supervisors. However, care must be taken that the structure of the **Guide** not be oriented entirely toward this group. A **Human Factors Guide** also can be used to advantage by other groups, including OTA management and OTA inspectors as well as aircraft **design** teams and designers of maintenance equipment. The document also could be used profitably in training operations.

Content. Three topics have been identified as most important for inclusion in a **Human Factors Guide**. These topics are:

- **Human** error in maintenance
- Information exchange and communications
- Maintenance training and practices

All topics must be given appropriate coverage in the **Guide**. Greatest attention, however, will be given to the three topics listed above.

Size. The **Human Factors Guide** should not be a large document and probably should not exceed 200 pages in length. A larger document might well impact use, particularly if the document is to be carried around within the maintenance facility. Current thinking is that supporting materials, which could be quite lengthy, would best be contained in a computerized data base in a CD-ROM system. With proper search strategies, data supporting the **Guide** could be obtained quite rapidly.

Style. Information within the **Human Factors Guide**, such as basic **human factors** principles applied to specific maintenance labor, should be presented concisely, possibly using a bullet format, with supporting illustrations. Introductory chapters and materials can be more in a running prose form. The language should be simple and straightforward English. This will make it more likely that the message is conveyed as intended. Use of simple English also will help should the **Guide** be translated into a foreign language for use in overseas maintenance activities.

6.5 REFERENCES

Air Transport Association. (1992). *Air Transport 1992. Annual report of the U.S. scheduled airline industry*. Washington, DC.

Office of Technology Assessment. (1988). *Safe skies for tomorrow.*(Report No. OTA-SET-381). Washington, DC: U.S. Government Printing Office.

Chapter Six
Appendix

Sample Section Of A Human Factors Guide

The following section illustrates the manner in which the above concepts and rules would be applied in the preparation of a section for the **Human Factors Guide**. The section is presented in highly abbreviated form simply to show the appearance and general content of a part of the **Guide**. This section does not indicate the depth of coverage planned for individual topics.

1.0 SECTION I: AREA AND TASK LIGHTING

1.1 Importance of Lighting in Industrial Operations

Lighting conditions in an industrial workplace are important both for worker productivity and for worker comfort. Numerous studies have examined the effect on worker productivity of varying levels of task illumination (see Cushman, 1987). In general, these studies show that performance under low illumination improves to a point as the illumination level is increased. Figure 1shows the reduced time required to complete a typical industrial task (reading a micrometer) as the level of illumination on the task is increased. Note that when the illumination reaches about 100 footcandles, no additional improvement is seen. In general, industrial tasks show smaller and smaller improvement in performance as illumination is increased. However, the point where performance finally levels off is task-dependent. Tasks that are visually difficult, as might be true for inspection activities, will require more light to achieve best performance than will easier tasks.

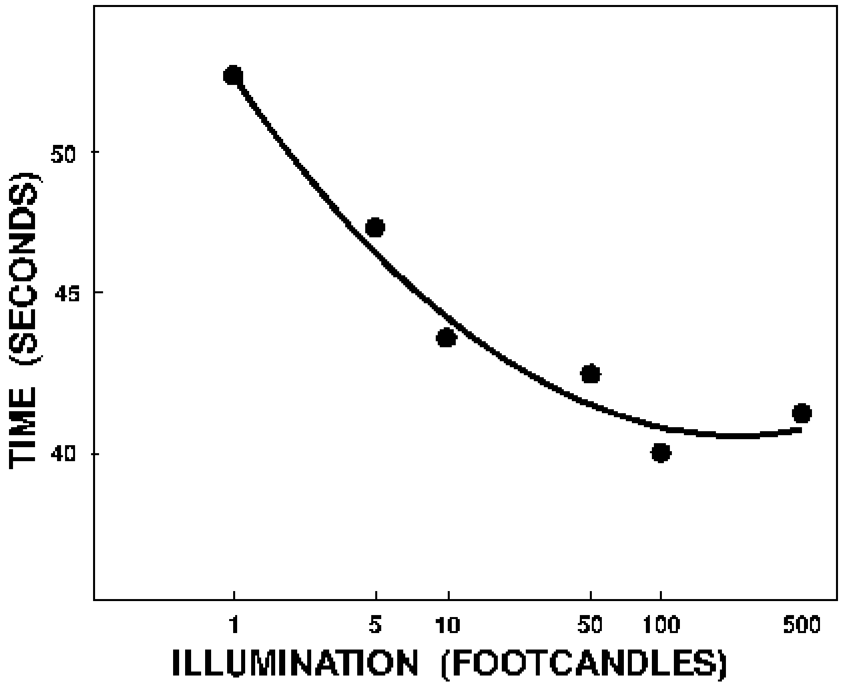

Figure 1 Effect of illumination level on time to complete a typical industrial task (micrometer readings). Adapted from *Sanders and McCormick, 1987.*

Research conducted to assess the effectiveness of illumination on performance must deal with two issues which can affect the results. First, motivational **factors** must be controlled. Subject, or workers, who know they are in a study will tend to perform better independent of the illumination level. Second, the age of subjects is important. Workers who are over 45 years of age will show more improvement with increasing illumination than will younger workers. If a work group contains older workers, illumination should be increased to account for this.

Recommendations for proper illumination levels for various activities have been prepared by the Illuminating Engineering Society and are presented in Table 1.

Activity	Level (footcandles)
Working spaces with occasional visual tasks	10 - 20
Performance of visual tasks of high contrast or large size	20 - 50
Performance of visual tasks of medium contrast	50 - 100
Performance of visual tasks of low contrast or very small size	100 - 200
Performance of visual tasks of low contrast and very small size over a prolonged period	200 - 500

Table 1 **Recommended Illuminance Values for Different Types of Activity. Adapted from** *Kantowitz & Sorkin, 1983*.

Sanders and McCormick (1987) point out problems in arriving at recommendations for adequate illumination to ensure proper task performance. Interestingly, they note that recommended levels continually increase through the years. Current recommended levels are about five times greater than levels recommended 30 years ago for the same tasks.

Even though proper levels of illumination are provided, task performance can be degraded if glare sources are present. Glare is of two types. Direct glare is produced when a bright light source is in the visual field. Indirect glare, often called reflected glare, is reflected from the work surface and reduces the apparent contrast of task materials. Either direct or indirect glare can degrade task performance. Table 2 offers suggestions concerning ways to control the effects of glare sources.

To Control Direct Glare	To Control Indirect Glare
Position lighting units as far from the operator's line of sight as practical	Avoid placing lights in the indirect-glare
Use several low-intensity lights instead of one bright one	Use lights with diffusing or polarizing lenses
Use lights that produce a batwing light distribution and position workers so that the highest light level comes from the sides, not front and back	Use surfaces that diffuse light, such as flat paint, non-gloss paper, and textured finishes
Use lights with louvers or prismatic lenses	Change the orientation of a workplace, task, viewing angle, or viewing direction until maximum visibility is achieved
Use indirect lighting	
Use light shields, hoods and visors at the workplace if other methods are impractical	

Table 2 Techniques for Controlling Glare, Adapted from *Rodgers, 1987*.

1.2 Lighting Conditions in Aviation Maintenance

A study of illumination conditions within major air carriers was accomplished as part of an OTA audit (Thackray, 1992). In these facilities, overhead lighting typically is supplied by mercury vapor, metal halide, or high-pressure sodium lights. The principal difference here is in terms of the color rendition of the lights. While color rendition is probably not too important for aircraft exterior maintenance tasks, the level of illumination could be. Table 3 shows average illumination levels measured at different maintenance work areas, both for day shifts and night shifts. Table 3also presents recommended illumination levels for aircraft repair and inspection tasks. Although slightly below recommended levels, the illumination for work on upper and lateral surfaces of an aircraft appear adequate. For repair and inspection conducted below wings, the fuselage, and within cargo and engine areas, measured illumination levels are not adequate and supplemental light sources are required. In general, supplemental lighting is provided through quartz halogen stand lights, dual 40-watt fluorescent stand fixtures, single hand-held fluorescent lamps, and flashlights.

Measured (Footcandles)	Day	Night
Hangar area	66	51
Below wings, fuselage and in cargo areas	26	15
Within fuselage	23	18
Visual inspection (2 D-cell flashlight)	100-500	

Recommended (Footcandles)	Min. Level
Aircraft repair, general	75
Aircraft visual inspection	
Ordinary area	50
Difficult	100
Highly difficult	200

Table 3 **Measured Illumination Levels at Major Air Carriers Compared with Recommended Levels. Adapted from** *Thackray, 1990.*

Use of supplemental lighting does not necessarily solve existing lighting problems. The OTA audit of major carriers found that supplemental lighting systems frequently were placed too far from the work being performed and were too few in number. The result was that, even with supplemental lighting, the illumination directly at the work site was less than adequate.

Aircraft inspectors generally use small flashlights as supplementary sources. At times, small lights mounted on headbands may be used. The flashlights provide illumination ranging from 100 to 500 footcandles and are acceptable for visual inspection. However, use of the flashlight means that one hand cannot be used for manipulation of the systems being inspected.

In an attempt to produce more even lighting within maintenance bays, some carriers have painted the walls and even the floors with a bright white reflective paint. While this does tend to reduce shadow effects, other problems can arise. The principal one is glare. Reflected light from bright sources produces glare which can both cause discomfort and reduce visibility of key features of the maintenance task. The glare tends to obscure or veil part of the visual task.

1.3 Guidelines

The goal of controlling **human** error in aviation maintenance requires that maintenance be conducted under proper lighting conditions. This is true both for area lighting, that which illuminates the full working area, and task lighting, that directed toward specific work activities. Improper or insufficient lighting can lead to mistakes in work tasks or can simply increase the time required to do the work. In a program directed toward proper lighting conditions, the following guidelines should be observed:

- Area lighting within a maintenance facility should be a minimum of 75 footcandles. A level of 100-150 footcandles is preferred.
- Care must be exercised to see that the light level available for night maintenance activities in particular does not drop below recommended levels. Any lighting studies must be conducted both during the day and at night.
- Task lighting for aircraft inspection requires a minimum of 100 footcandles of illumination. For difficult inspections or fine machine work, 200-500 footcandles of illumination is necessary.
- Supplemental lighting must be adequate for the task at hand, best judged by the worker. Task lighting should be placed close to the work being done and, if feasible, should leave both of the worker's hands free for the work. If systems must be manipulated, lights mounted on headbands are preferred to flashlights.
- If the workforce contains a substantial percentage of older workers, i.e. those greater than 45 years of age, recommended lighting levels should be increased, probably on the order of 50 percent.
- Glare sources should be controlled. Supplemental lighting should be placed as far from a worker's line of sight as practical. Reflected glare can be changed by reorienting the work surface or changing the position of lights. Worker complaints are the best means for identifying offending glare sources.

1.4 Procedures for Evaluating Light Conditions

The best procedure for determining if lighting conditions are adequate is through the services of either the industrial hygiene department or the safety department of the air carrier. Individuals in these departments typically are trained in procedures for conducting an environmental audit, possess the necessary measurement equipment, and understand the problems involved in obtaining meaningful measurements. Specialists from these departments also will be able to provide a proper evaluation of the audit results.

If the services of specialists are not available, maintenance managers can assess lighting conditions themselves. Photometric equipment is available which will provide accurate (generally plus or minus five percent) measurement of facility lighting. Illuminometers/photometers are available commercially for a price in the order of $1,000. Catalogs of scientific equipment describe these items.

1.5 REFERENCES

Cushman, W.H. & Crist, B. (1987). Illumination. In G. Salvendy (Ed.), *Handbook of human factors* (pp. 670-695). New York: John Wiley & Sons.

Kantowitz, B.H. & Sorkin, R.D. (1983). *Human factors: Understanding people-system relationships.* New York: Wiley & Sons.

Rodgers, S.H. & Eggleton, E.M. (Eds.). (1983). Ergonomic **design** for people at work. (Vol. 1). Rochester, NY: Eastman Kodak Co.

Sanders, M.S. & McCormick, E.J. (1987). *Human factors in engineering and design* (6th ed.). New York: McGraw-Hill Book Co.

Thackray, R.I. (1992). *Human factors evaluation of the work environment of operators engaged in the inspection and repair of aging aircraft.*(Report No. DOT/FAA/AM-92/3). Washington, DC: Federal Aviation Administration.